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EVALUATION OF A TECHNIQUE FOR SAMPLING LOW CONCENTRATIONS OF ORGANIC VAPORS IN AMBIENT AIR

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Following contamination of the Morris Forman Wastewater Treatment Plant, Louisville, KY, by Hexachlorocyclopentadiene and Octachlorocyclopentene, large volumes of these contaminants were isolated on the plant site. An extensive program of monitoring ambient air was developed for the protection of plant personnel and the general public during destruction of the material with on-site equipment. This document describes in detail the technique used to monitor the air and compares that technique with OSHA routine air monitoring techniques used in the workplace.

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EVALUATION OF A TECHNIQUE FOR SAMPLING LOW CONCENTRATIONS OF ORGANIC VAPORS IN AMBIENT AIR

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1.0 SUMMARY

Under Task 1 of Contract 68-02-2618, assistance was provided during the spring of 1977 in sampling and analysis supporting the disposal of a large amount of sewage sludge contaminated by hexachlorocyclopentadiene and octachlorocyclopentene and located at the Morris Forman Wastewater Treatment Plant, Louisville, Kentucky. During the course of the disposal operations, it became necessary to provide rapid sampling and analysis for the two sewage sludge contaminants in ambient air on the facility grounds.[1] A rapid method of sampling was developed using a miniature glass impinger tube, containing some 4 ml of hexane, coupled to a portable metering pump. The resulting device was found to be highly satisfactory in that samples could be taken in ten minutes with the resulting extract in a form ready for immediate injection into a gas chromatograph.[1]

The apparent field utility of the above technique led to its evaluation and comparison with Chromosorb 102 solid adsorbent, as reported herein, in order to assess its potential applicability to situations where rapid analysis of trace organics in ambient air is mandatory. An evaluation test bed consisting of two parallel sampling trains was constructed so that effects of sampling conditions and other parameters could be determined with minimum effects of potential external interferences and source variations.

The evaluation study has been completed with the result that, with hexane as the impinger solvent, the device was found to have an extraction efficiency in excess of 97 percent when operated at ambient temperature (~ 20°C). Further, when benzene was used as the impinger solvent, the extraction efficiency was

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(1) Whitmore, F.C., R.L. Durfee and M.N. Khattak, "Region IV Support at Morris Forman Wastewater Treatment Plant, Louisville, Kentucky", Final Task Report, Task 1, Contract No. 68-02-2618. Prepared by Versar Inc., Springfield, Va. (1977).

found to be essentially 100 percent; this was also observed when the impinger tube, using hexane, was operated at the reduced temperature of an ice-acetone bath. Finally, the device was found to yield sampling efficiency that closely approximated that of Chromasorb 102 solid adsorbent without introducing the added steps of desorption and solvent concentration that are required with the latter.

The technique thus appears to be useful for sampling low concentrations of organic vapors (effects of particulates were not studied) in ambient air, and provides samples which can be directly injected into a gas chromatograph so that analytical results are made available in a very short time. Further, effectiveness of the technique appears not to be limited by solvent choice or by sampling conditions over the ranges covered in these tests.

2.0 CONCLUSIONS

The data presented in Section 5.0 of this report indicate that the Versar sampler is capable of extracting a minimum of about 97 percent of the chlorinated benzenes from a passing air stream under any set of experimental conditions within the range covered by these experiments.

The sampler compares quite favorably with the Chromasorb 102 device in that there was only a 2 percent variation observed between the results obtained with the two sampling techniques.

It appears that the efficiency of the device is significantly enhanced by the use of benzene (with higher boiling point) as the impinger fluid as compared with the use of hexane. Further, when the device is operated at low temperatures, the efficiency approaches that of the solid sorber. In addition, air flow rate had a negligible effect on the effectiveness of the sampler (over the range covered).

In summary, the following conclusions may be stated:

1. The sampling technique is a highly useful device that compares favorably with the OSHA Chromasorb 102 capsule solid sorber.
2. The extracted organics remain in stable solution in the impinger solution even while the latter is evaporated.
3. Such parameters as pumping rate, initial and final volume of the impinger solvent have little effect on the extraction efficiency of the device or on the stability of the extracted materials.
4. The geometry of the device is not of great importance in efficiency of extraction or the stability of the extract.

It should be noted that experience thus far with the technique has not included the sampling of either particulates or relatively volatile organic compounds. Thus, the effectiveness of the system toward quantitative removal of these types of materials from ambient air cannot be stated at present.

3.0 BACKGROUND AND APPROACH

3.1 General

The determination of the ambient air concentration of various toxic materials usually involves either the taking of a grab sample of the ambient air or the collection of a composite sample by passing a metered air sample through a suitable impinger system containing an appropriate solvent. Once the sample has been taken it is usually analyzed by use of the gas chromatograph coupled to a suitable detector. There are several steps to this process that are not obvious to the above description - steps dictated by the nature of the chromatograph. It is the primary purpose of the technique discussed below to simplify some of these intermediate steps and to obviate others.

The gas chromatograph (GC) derives its great utility in analysis by virtue of its ability to effect a temporal separation of the individual components of a complex mixture. It will present each component to a suitable detector at a time from injection that is characteristic of that component. In order that the spatial separation of each component be complete it is essential that the duration of the injection pulse be very small in comparison to the retention time for the earliest component to arrive. This requirement obviously directs that the quantity of sample that is injected be very small; typically of the order of several microliters.

The sensitivity of the GC derives both from the ultimate peak separation effected by the column and from the sensitivity of the detector used. To illustrate this point, the electron capture detector (ECD), normally used to detect halogenated organic compounds, was found to have an absolute detection limit for hexachlorocyclopentadiene (HCCP) of the order of 1.5×10^{-12} grams. Thus, a solution that contains a concentration of HCCP that will yield a barely detectable response in the detector will, for a 2 microliter injection, have to have a concentration of

$$C_{lim} = \frac{1.5 \times 10^{-12}}{2 \times 10^{-6}} = 0.75 \times 10^{-6} \text{ gm/liter.}$$

In most cases, the solution that is chromatographed is measured in ml rather than in liters, so that

$$C_{lim} = 0.75 \times 10^{-9} \text{ gm/ml.}$$

Normal practice with GC analysis involves removing the compounds of interest from the original sample matrix by use of a suitable solvent and then concentrating the extract to a final volume of five (or less) ml from which the injected sample is taken. The concentration process is carried out by a very gentle evaporation of the solution, gentle in order to not lose the contaminants of interest during the concentrating process.

When one applies the above to a measurement of the ambient concentration of a toxic material in air, the following steps are involved: (a) taking the sample; (b) extracting the components of interest from the sample; (c) concentrating the extract; and (d) injecting a sample into the GC. It should be pointed out that if the intermediate steps between collection and final measurement were not included, the result would be a considerable loss of sensitivity. For instance, if a 2 microliter sample of contaminated gas were directly injected into the GC, the C_{lim} would be given as

$$C_{lim} = 0.75 \times 10^{-6} \text{ gm/liter}$$

or something of the order of 0.6 ppm. On the other hand, if the HCCP in a liter of air were extracted into 1 ml of solvent from which a 2 microliter sample were injected, the C_{lim} would be decreased by a factor of 1000; i.e., the sensitivity of detection would be increased by a factor of 1000.

Although the general methods of ambient air sampling do, in fact, utilize the increase in sensitivity that accompanies solvent extraction, it is the usual practice to collect the ambient air sample in a plastic or metal container, which is then transferred to the laboratory for extraction and analysis. During this interval of exposure of the air sample to the walls of the container, it is possible to alter the sample by losses to the walls, losses from the walls or even conversions due to wall effects.

It is possible to obviate the disturbing effects of the container walls if the sample is collected in a suitable stripping medium at the moment that it is collected. In this way, that which is transferred to the laboratory is the already solvent-stripped sample which is usually relatively stable. The standard methods that are practiced for stripping-collection involve the use of impingers that contain several tens or hundreds of ml of solvent, or on solid adsorbers (such as Chromasorb 102). In the case of the fluid impingers, it is still necessary to significantly reduce the volume of the impinger fluid prior to injection into the GC. In the case of the solid adsorbers, it has been found that, in general, solvents that are compatible with the ECD are not suitable for desorption from the solid sorbants (Chromasorb 102) so that detection of the eluted stream from the GC is usually accomplished using the flame photometric detector (FPD). The relatively lower sensitivity of the FPD as compared to the ECD for the detection of halogenated organic compounds results in the necessity of long sampling times in conjunction with the solid sorbents.

3.2 Ambient Air Sampling Device

It is possible to combine the liquid impinger system for stripping the gas sample with the gentle evaporative concentration of the solution, and thus to greatly increase the speed and simplicity of the measurements. A typical embodiment of this concept is shown in Figure 3-1. The simplest form of this device involves a gas washing bottle, capacity between 100 and 250 ml, a calibrated and glass-stoppered centrifuge tube, and a portable gas pump such as is used in personnel samplers. The impinger tube of the gas washing bottle is drawn down to a rather fine point. In operation, about 4 ml of pesticide-grade hexane is placed in the tube, the impinger tube inserted and pumping begun. At a rate of 200 ml/min., it is found that roughly half of the hexane is evaporated in ten minutes, during which time a sample of 2 liters of air has been scrubbed. The remaining 2 ml, whose volume can be determined from the calibration markers, is then used as the injection preparation. The resulting sensitivity of this system is found to be, for hexachlorocylopentadiene (HCCP), below a part per billion in ambient air.

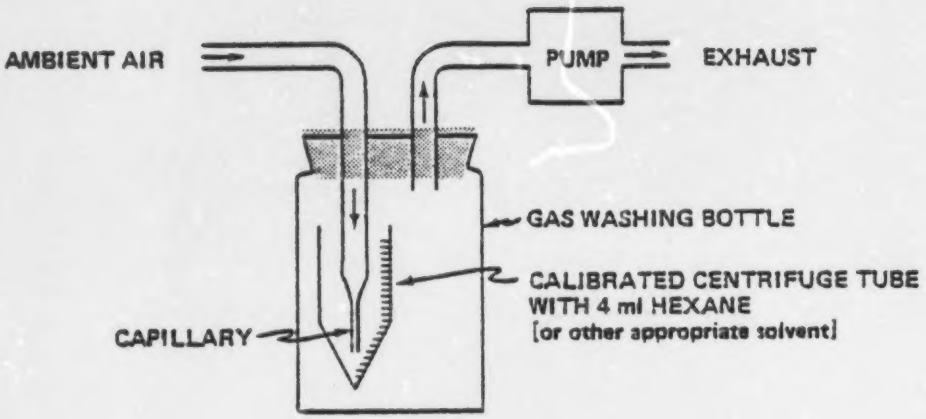

Figure 3-1
Schematic Diagram of Ambient Air Sampler

In view of the ease with which this device can be used and the speed with which ambient samples may be taken, it was deemed desirable to conduct a series of tests designed to determine the effect of various parameters on the extraction efficiency of the device and to conduct a quantitative comparison of this device with the Chromasorb 102 solid absorber system. The methods used and the results obtained from these tests are presented in Sections 4.0 and 5.0, respectively.

4.0 EVALUATION TESTS

4.1 Equipment

A number of parameters and experimental conditions might be expected to affect the utility of the sampling technique described in Section 3.2. A study of the effect of several of these parameters has been conducted using the laboratory set up as depicted in Figure 4-1. A dual (parallel system) was selected for these tests in order to obviate the effect of possible variations in the source concentrations with time. By directly comparing two systems, the effect of the variable under study may best be separated from interference due to other disturbing influences.

The source selected for this work consisted of a small impinger container to which was added a known concentration of the three test compounds in pure hexane. The impinger tube was so arranged as to pass the incoming stream of pure air over the top of the solution so as to enhance the evaporation of that solution and thus to admit the solvent and the solutes to the passing air stream. Although several mixtures of organics were considered as test compounds, the final selection consisted of a mixture of a trichlorobenzene and two tetrachlorobenzenes. Specifically, the compounds that were used were 1,2,4-trichlorobenzene, 1,2,3,4-tetrachlorobenzene and 1,2,4,5-tetrachlorobenzene. These compounds are designated as (1), (2) and (3) respectively in what follows.

Each of the two samplers was followed by a backup impinger system that consisted of three miniature impingers in series, each containing 10 ml of spectrograde benzene and the whole maintained at constant temperature. The function of this backup train was the determination of the efficiency with which the sampler, under a particular combination of conditions, was capable of removing the three test compounds from the passing air stream.

Each of the two parallel sampling trains was equipped with a precision flow regulator to allow complete control of the pumping rate in each train.

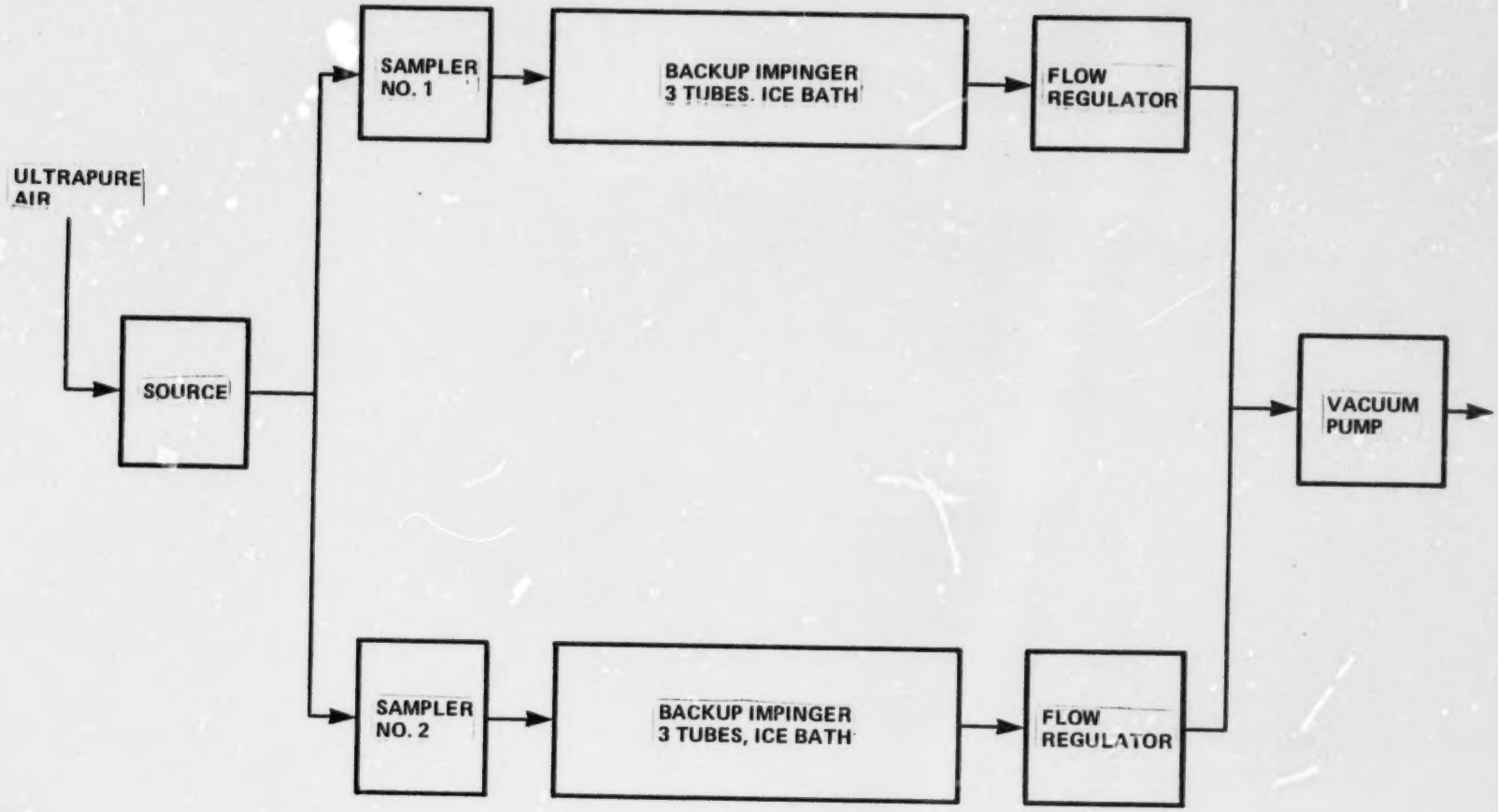

FIGURE 4 - 1 SCHEMATIC OF LABORATORY TEST SET-UP

4.2 Parameters and Conditions

As a result of the field tests of this device,[1] it was determined that the following parameters should be of importance in the efficiency of the sampler: solvent choice, pumping speed, sampling time, orifice geometry, sampler temperature, and the initial and final volume of the impinger solvent. A test program was designed to allow the evaluation of each of these parameters. The parametric designations selected, which are tabulated on Table 4-1, were combined into the succinct description of the individual experiments as is shown in Table 4-2.

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(1) Whitmore, F.C., R.L. Durfee and M.N. Khattak, "Region IV Support at Morris Forman Wastewater Treatment Plant, Louisville, Kentucky", Final Task Report, Task 1, Contract No. 68-02-2618. Prepared by Versar Inc., Springfield, Va. (1977).

Table 4-1

Parameter Designation for Sampling Technique Evaluation Test Series

Parameter	Designation	Choice	Designation	Choice
Impinger solvent	A	hexane	a	benzene
Initial solvent volume	B	4 ml	b	less than 4 ml
Pumping rate	C	1 SCFH	c	less than 1 SCFH
Sampling time	D	15 min	d	more than 15 min
Final solvent volume	E	1 ml	e	less than 1 ml
Operating temperature	F	ambient	f	ice-acetone
Impinger tube diameter	G	0.2 cm	g	less than 0.2 cm
Initial concentration in impinger	H	zero	h	non-zero
Sampler	I	Versar	i	Chromasorb 102

Table 4-2

Experimental Program

Experiment/Parameter	Sampler No. 1*	Sampler No. 2*
1. Reproducibility	ABCDEFGHI	ABCDEFGHI
2. Reproducibility	ABCDEFGHI	ABCDEFGHI
3. Final Solvent Volume	ABCDEFGHI	ABCDeFGHI
4. Pumping Rate	ABCDEFGHI	ABcDEFGHI
5. Impinger Solvent	ABCDEFGHI	aBCDEFGHI
6. Ambient Temperature	ABCDEFGHI	ABcDefGHI
7. Sampling Time	ABcDEFGHI	ABodEFGHI
8. Impinger Tube Diameter	ABCDEFGHI	ABCDEFgHI
9. Sample Stability	ABCDEFGhI	
10. Sample Stability	ABCDEFGhI	
11. Comparison with Chromasorb 102	ABCDEFGHI	CDFHi

*Key to conditions and parameters is presented on Table 4-1.

5.0 EXPERIMENTAL RESULTS

The large number of experimental data points obtained in the course of these experiments, and the necessity of stipulating a variety of parametric values for each experiment, suggested that the most convenient method of presenting the resulting data is in a tabular form. Tables 5-1 through 5-11 present the summarized data from each of the eleven experiments. Note that the three test compounds designated as (1), (2) and (3) in Section 4.1 are so identified in each of the tables.

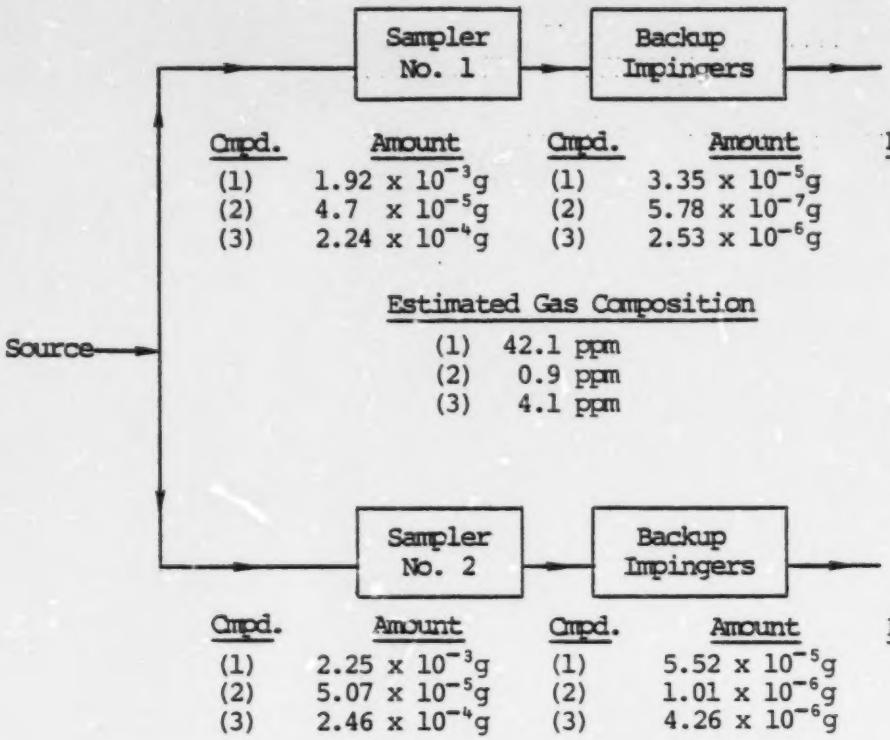
In each case, the residual impinger solvent in the sampler, as well as the combined impinger solutions in the three backup impingers, was extracted for analysis. The quantities that are cited in each table are the total quantity of each of the three components of the test mixture that was found in either the sampler or the backup impinger train. All analyses were carried out by gas chromatography using the following column operating parameters.

Oven Temperature	150°C
Detector Temperature	300°C
Injection Port Temperature	200°C
Gas Flow Rate	50 cc/min
Column	OV17 + F1 on Chromasorb 101

The ECD was calibrated using authentic compounds as was the retention time on the column.

Table 5-1

Results of Test No. 1: Reproducibility of Sampling



Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	1.92×10^{-3}g	(1)	3.35×10^{-5}g	98.3
(2)	4.7×10^{-5}g	(2)	5.78×10^{-7}g	98.8
(3)	2.24×10^{-4}g	(3)	2.53×10^{-6}g	98.8

Estimated Gas Composition

(1) 42.1 ppm
(2) 0.9 ppm
(3) 4.1 ppm

Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	2.25×10^{-3}g	(1)	5.52×10^{-5}g	97.6
(2)	5.07×10^{-5}g	(2)	1.01×10^{-6}g	98.0
(3)	2.46×10^{-4}g	(3)	4.26×10^{-6}g	98.1

Estimated Gas Composition

(1) 44.3 ppm
(2) 0.8 ppm
(3) 3.7 ppm

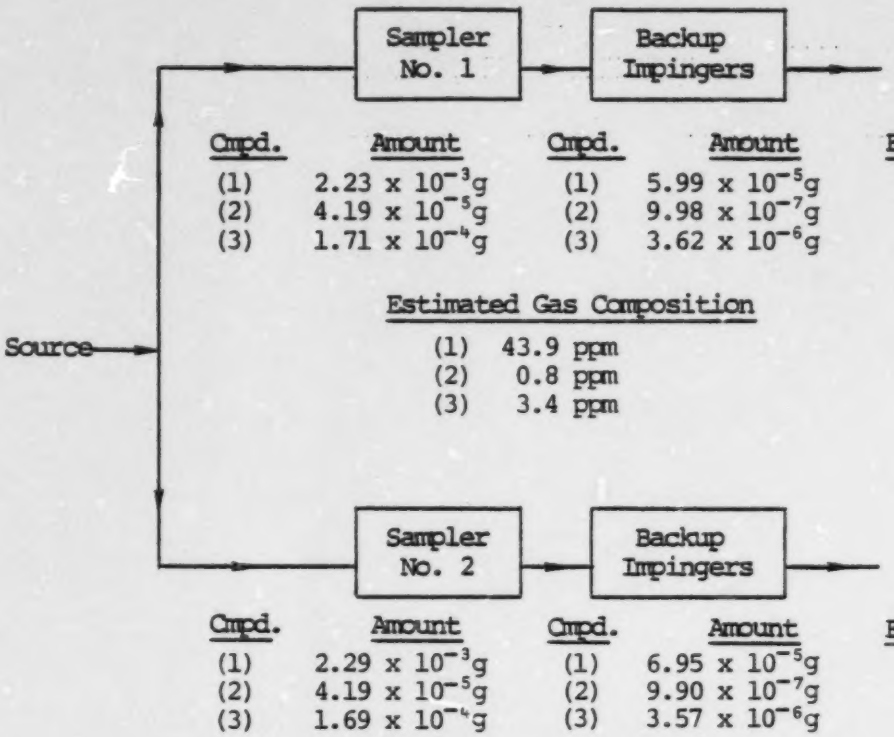
EXPERIMENTAL CONDITIONS

Parameter	Sampler No. 1	Sampler No. 2
Solvent	hexane	hexane
Initial volume	4 ml	4 ml
Pump rate	0.9 SCFH	1.0 SCFH
Sampling time	15 min.	15 min.
Final volume	1.0 ml	1.0 ml
Backup solvent	benzene	benzene
Operating temperature	ambient	ambient
Impinger diameter	0.2 cm	0.2 cm

*Defined as amount collected in sampler divided by total amount collected from that stream, expressed as percentage.

Table 5-2

Results of Test No. 2: Reproducibility of Sampling



Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	2.23×10^{-3}g	(1)	5.99×10^{-5}g	97.4
(2)	4.19×10^{-5}g	(2)	9.98×10^{-7}g	97.7
(3)	1.71×10^{-4}g	(3)	3.62×10^{-6}g	97.9

Estimated Gas Composition

(1) 43.9 ppm
(2) 0.8 ppm
(3) 3.4 ppm

Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	2.29×10^{-3}g	(1)	6.95×10^{-5}g	97.1
(2)	4.19×10^{-5}g	(2)	9.90×10^{-7}g	97.7
(3)	1.69×10^{-4}g	(3)	3.57×10^{-6}g	97.9

Estimated Gas Composition

(1) 45.2 ppm
(2) 0.8 ppm
(3) 3.3 ppm

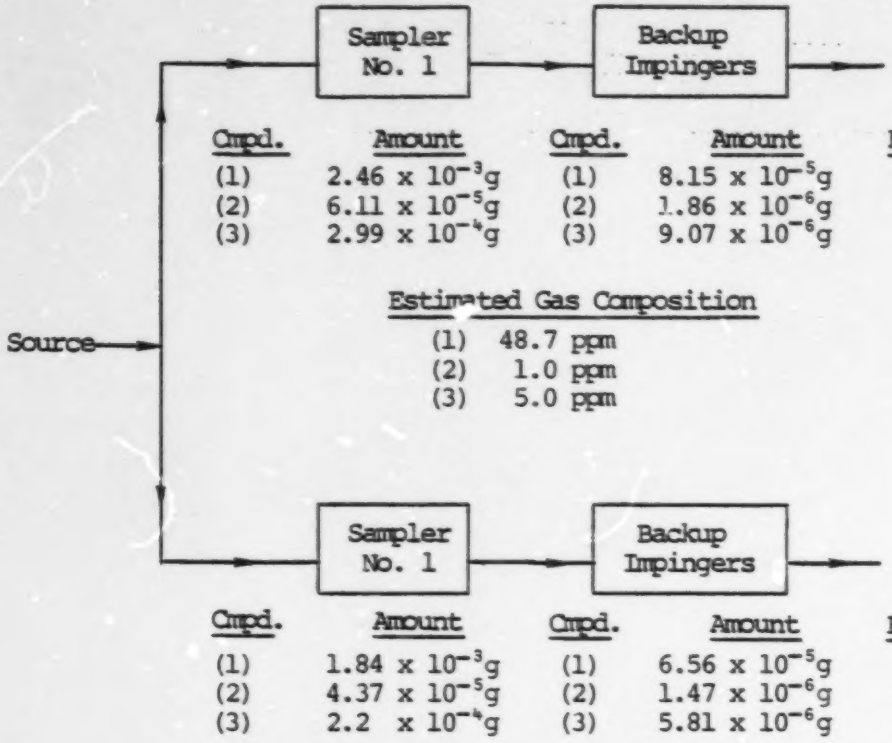
EXPERIMENTAL CONDITIONS

Parameter	Sampler No. 1	Sampler No. 2
Solvent	hexane	hexane
Initial volume	4 ml	4 ml
Pump rate	1.0 SCFH	1.0 SCFH
Sampling time	15 min.	15 min.
Final volume	1 ml	1 ml
Backup solvent	benzene	benzene
Operating temperature	ambient	ambient
Impinger diameter	0.2 cm	0.2 cm

*Defined as amount collected in sampler divided by total amount collected from that stream, expressed as percentage.

Table 5-3

Results of Test No. 3: Effect of Impinger Solvent Volume Reduction



Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	2.46×10^{-3}g	(1)	8.15×10^{-5}g	96.8
(2)	6.11×10^{-5}g	(2)	1.86×10^{-6}g	97.0
(3)	2.99×10^{-4}g	(3)	9.07×10^{-6}g	97.1

Estimated Gas Composition

(1) 48.7 ppm
(2) 1.0 ppm
(3) 5.0 ppm

Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	1.84×10^{-3}g	(1)	6.56×10^{-5}g	96.6
(2)	4.37×10^{-5}g	(2)	1.47×10^{-6}g	96.7
(3)	2.2×10^{-4}g	(3)	5.81×10^{-6}g	97.4

Estimated Gas Composition

(1) 49.1 ppm
(2) 1.0 ppm
(3) 5.8 ppm

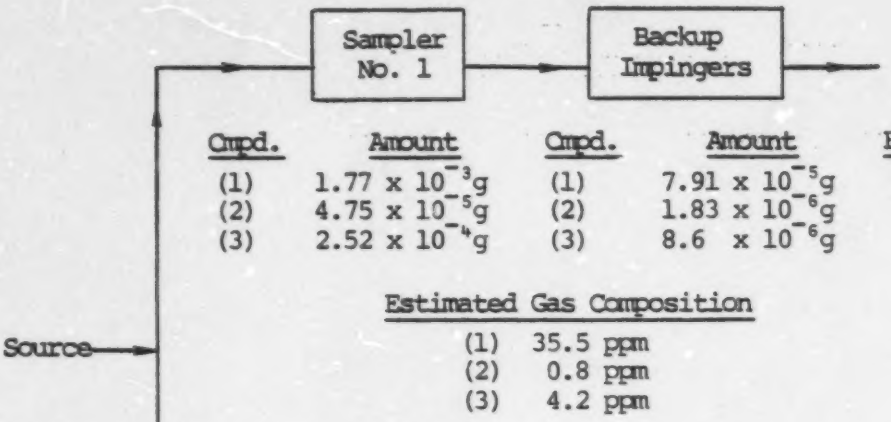
EXPERIMENTAL CONDITIONS

Parameter	Sampler No. 1	Sampler No. 2
Solvent	Hexane	Hexane
Initial volume	4 ml	3.5 ml
Pump rate	1 SCFH	0.75 SCFH
Sampling time	15 min.	15 min.
Final volume	1 ml	0.2 ml
Backup solvent	benzene	benzene
Operating temperature	ambient	ambient
Impinger diameter	0.2 cm	0.2 cm

*Defined as amount collected in sampler divided by total amount collected from that stream, expressed as percentage.

Table 5-4

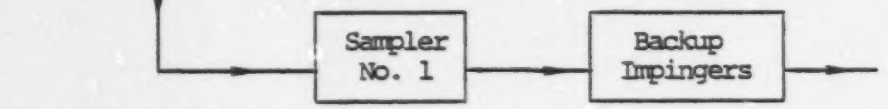
Results of Test No. 4: Effect of Pumping Rate



Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	1.77×10^{-3} g	(1)	7.91×10^{-5} g	95.7
(2)	4.75×10^{-5} g	(2)	1.83×10^{-6} g	96.3
(3)	2.52×10^{-4} g	(3)	8.6×10^{-6} g	96.7

Estimated Gas Composition

(1) 35.5 ppm
(2) 0.8 ppm
(3) 4.2 ppm



Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	9.39×10^{-4} g	(1)	5.26×10^{-7} g	99.9
(2)	2.15×10^{-5} g	(2)	Not detectable	> 99.9
(3)	1.14×10^{-4} g	(3)	3.33×10^{-8} g	99.9

Estimated Gas Composition

(1) 36.5 ppm
(2) 0.7 ppm
(3) 3.7 ppm

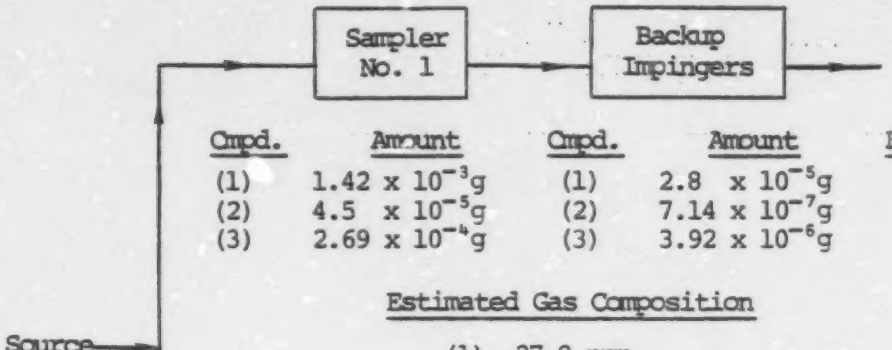
EXPERIMENTAL CONDITIONS

Parameter	Sampler No. 1	Sampler No. 2
Solvent	hexane	hexane
Initial Volume	4 ml	4 ml
Pump rate	1 SCFH	0.25 SCFH
Sampling time	15 min	30 min
Final volume	1 ml	1.7 ml
Backup solvent	benzene	benzene
Operating temperature	ambient	ambient
Impinger diameter	0.2 cm	0.2 cm

*Defined as amount collected in sampler divided by total amount collected from that stream, expressed as percentage.

Table 5-5

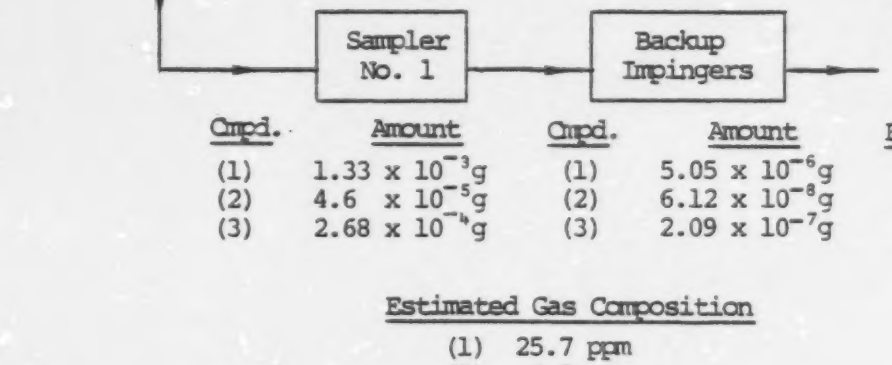
Results of Test No. 5: Effect of Impinger Solvent Selection



Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	1.42×10^{-3}g	(1)	2.8×10^{-5}g	98.1
(2)	4.5×10^{-5}g	(2)	7.14×10^{-7}g	98.4
(3)	2.69×10^{-4}g	(3)	3.92×10^{-6}g	98.6

Estimated Gas Composition

(1) 27.8 ppm
(2) 0.7 ppm
(3) 4.4 ppm



Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	1.33×10^{-3}g	(1)	5.05×10^{-6}g	99.6
(2)	4.6×10^{-5}g	(2)	6.12×10^{-8}g	99.9
(3)	2.68×10^{-4}g	(3)	2.09×10^{-7}g	99.9

Estimated Gas Composition

(1) 25.7 ppm
(2) 0.7 ppm
(3) 4.3 ppm

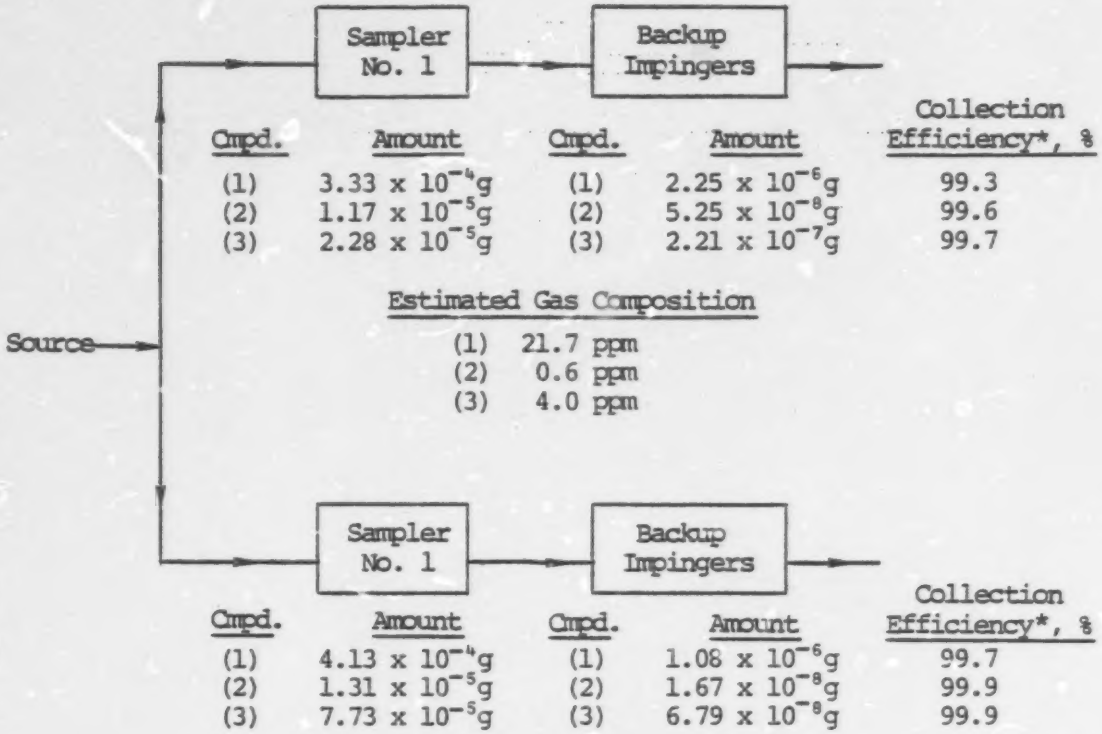
EXPERIMENTAL CONDITIONS

Parameter	Sampler No. 1	Sampler No. 2
Solvent	hexane	hexane
Initial volume	4 ml	4 ml
Pump rate	1 SCFH	1 SCFH
Sampling time	15 min	15 min
Final volume	1 ml	2.2 ml
Backup solvent	benzene	benzene
Operating temperature	ambient	ambient
Impinger diameter	0.2 cm	0.2 cm

*Defined as amount collected in sampler divided by total amount collected from that stream, expressed as percentage.

Table 5-6

Results of Test No. 6: Effect of Sampling Time



Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	3.33×10^{-4}g	(1)	2.25×10^{-6}g	99.3
(2)	1.17×10^{-5}g	(2)	5.25×10^{-8}g	99.6
(3)	2.28×10^{-5}g	(3)	2.21×10^{-7}g	99.7

Estimated Gas Composition

(1) 21.7 ppm
(2) 0.6 ppm
(3) 4.0 ppm

Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	4.13×10^{-4}g	(1)	1.08×10^{-6}g	99.7
(2)	1.31×10^{-5}g	(2)	1.67×10^{-8}g	99.9
(3)	7.73×10^{-5}g	(3)	6.79×10^{-8}g	99.9

Estimated Gas Composition

(1) 20.1 ppm
(2) 0.54 ppm
(3) 3.2 ppm

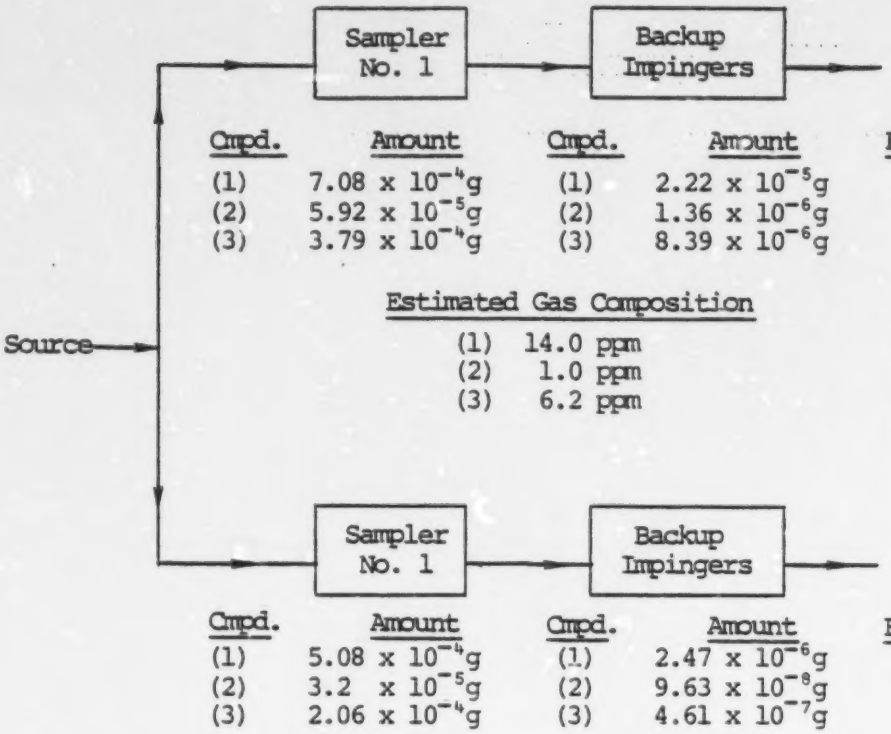
EXPERIMENTAL CONDITIONS

Parameter	Sampler No. 1	Sampler No. 2
Solvent	hexane	hexane
Initial volume	4 ml	4 ml
Pump rate	0.3 SCFH	0.2 SCFH
Sampling time	15 min	30 min
Final volume	2 ml	2 ml
Backup solvent	benzene	benzene
Operating temperature	ambient	ambient
Impinger diameter	0.2 cm	0.2 cm

*Defined as amount collected in sampler divided by total amount collected from that stream, expressed as percentage.

Table 5-7

Results of Test No. 7: Effect of Sampling Temperature



Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	7.08×10^{-4}g	(1)	2.22×10^{-5}g	97.0
(2)	5.92×10^{-5}g	(2)	1.36×10^{-6}g	97.7
(3)	3.79×10^{-4}g	(3)	8.39×10^{-6}g	97.9

Estimated Gas Composition

(1) 14.0 ppm
(2) 1.0 ppm
(3) 6.2 ppm

Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	5.08×10^{-4}g	(1)	2.47×10^{-6}g	99.6
(2)	3.2×10^{-5}g	(2)	9.63×10^{-8}g	99.7
(3)	2.06×10^{-4}g	(3)	4.61×10^{-7}g	99.8

Estimated Gas Composition

(1) 16.5 ppm
(2) 0.9 ppm
(3) 5.6 ppm

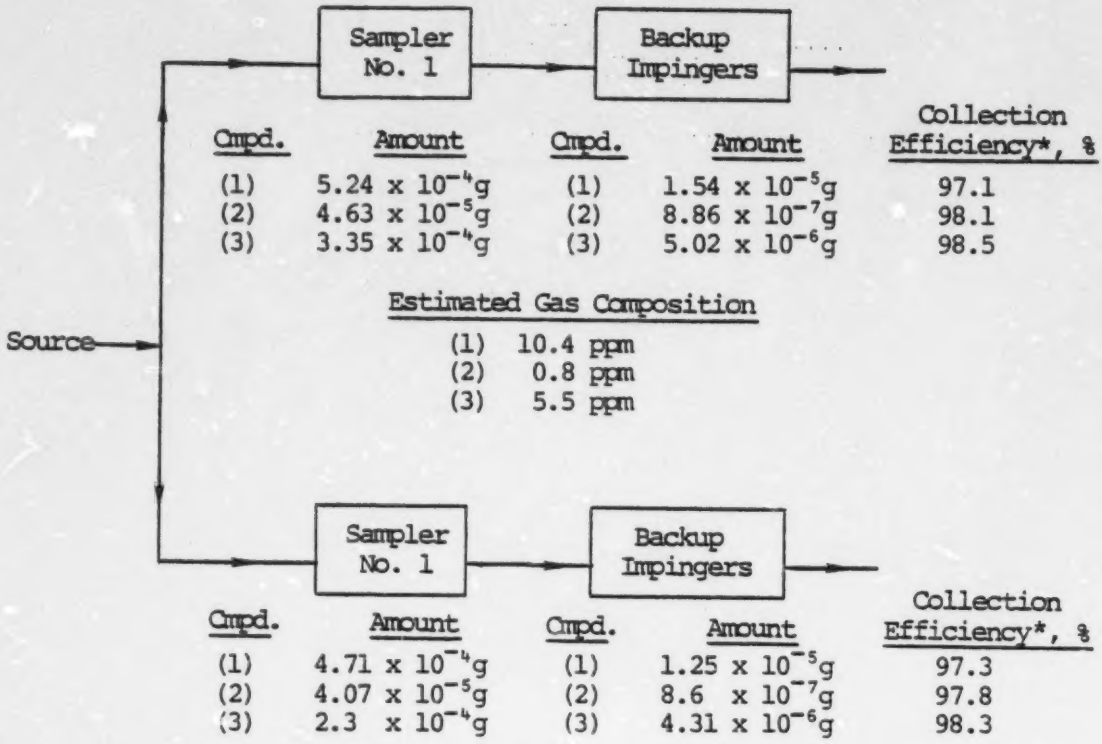
EXPERIMENTAL CONDITIONS

Parameter	Sampler No. 1	Sampler No. 2
Solvent	hexane	hexane
Initial volume	4 ml	4 ml
Pump rate	1 SCFH	0.60 SCFH
Sampling time	15 min	15 min
Final volume	1 ml	2.5 ml
Backup solvent	benzene	benzene
Operating temperature	ambient	ice-acetone
Impinger diameter	0.2 cm	0.2 cm

*Defined as amount collected in sampler divided by total amount collected from that stream, expressed as percentage.

Table 5-8

Results of Test No. 8: Effect of Impinger Geometry



Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	5.24×10^{-4}g	(1)	1.54×10^{-5}g	97.1
(2)	4.63×10^{-5}g	(2)	8.86×10^{-7}g	98.1
(3)	3.35×10^{-4}g	(3)	5.02×10^{-6}g	98.5

Estimated Gas Composition

(1) 10.4 ppm
(2) 0.8 ppm
(3) 5.5 ppm

Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	4.71×10^{-4}g	(1)	1.25×10^{-5}g	97.3
(2)	4.07×10^{-5}g	(2)	8.6×10^{-7}g	97.8
(3)	2.3×10^{-4}g	(3)	4.31×10^{-6}g	98.3

Estimated Gas Composition

(1) 10.9 ppm
(2) 0.8 ppm
(3) 4.5 ppm

EXPERIMENTAL CONDITIONS

Parameter	Sampler No. 1	Sampler No. 2
Solvent	hexane	hexane
Initial volume	4 ml	4 ml
Pump rate	1 SCFH	0.85 SCFH
Sampling time	15 min	15 min
Final volume	1 ml	1 ml
Backup solvent	benzene	benzene
Operating temperature	ambient	ambient
Impinger diameter	0.1 cm	0.25 cm

*Defined as amount collected in sampler divided by total amount collected from that stream, expressed as percentage.

Table 5-9

Results of Test No. 9: Stability of Collected Samples Under Operating Conditions; High Concentration

Initial Conditions

Sampler	Backup Impinger
(1) 8.46×10^{-6}g	(1) Non detected
(2) 7.05×10^{-6}g	(2) Non detected
(3) 5.79×10^{-6}g	(3) Non detected

Final Conditions

Sampler	Backup Impinger
(1) 8.0×10^{-6}g	(1) 1.22×10^{-7}g
(2) 6.69×10^{-6}g	(2) 5.07×10^{-8}g
(3) 5.49×10^{-6}g	(3) 2.63×10^{-8}g

Retention Efficiency

(1) 94.6%
(2) 94.9%
(3) 94.8%

Operating Conditions

Solvent	hexane
Initial volume	4 ml
Pump rate	1 SCFH
Pumping time	15 min
Backup solvent	benzene
Operating temperature	ambient
Impinger diameter	0.2 cm

Table 5-10

Results of Test No. 10: Stability of Collected Sample Under Operating Conditions; Low Concentration

Initial Conditions

Sampler	Backup Impinger
(1) 1.11×10^{-6}g	(1) Non detected
(2) 9.3×10^{-7}g	(2) Non detected
(3) 6.76×10^{-7}g	(3) Non detected

Final Conditions

Sampler	Backup Impinger
(1) 1.05×10^{-6}g	(1) 4.6×10^{-8}g
(2) 8.45×10^{-7}g	(2) 1.47×10^{-8}g
(3) 6.55×10^{-7}g	(3) 7.3×10^{-9}g

Retention Efficiency

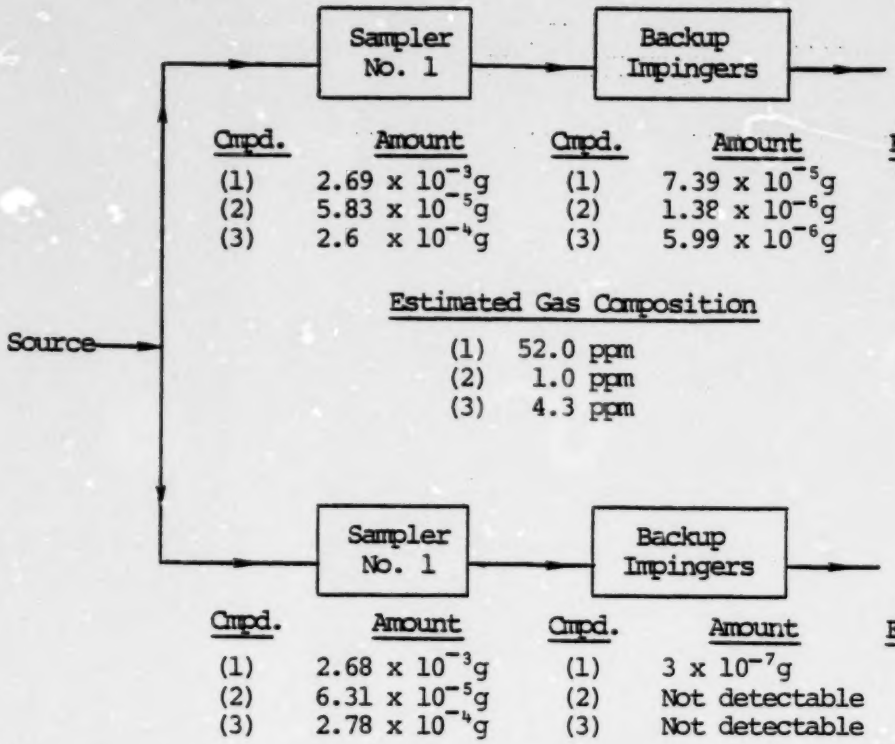
(1) 95%
(2) 91%
(3) 97%

Operating Conditions

Solvent	hexane
Initial volume	0.75 ml
Pump rate	1 SCFH
Pump time	15 min
Backup solvent	benzene
Operating temperature	ambient
Impinger diameter	0.2 cm

Table 5-11

Results of Test No. 11: Comparison of Sampler to OSHA Chromasorb 102 Capsule Sampler



Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	2.69×10^{-3}g	(1)	7.39×10^{-5}g	97.3
(2)	5.83×10^{-5}g	(2)	1.38×10^{-6}g	97.7
(3)	2.6×10^{-4}g	(3)	5.99×10^{-6}g	97.7

Estimated Gas Composition

(1) 52.0 ppm
(2) 1.0 ppm
(3) 4.3 ppm

Cmpd.	Amount	Cmpd.	Amount	Collection Efficiency*, %
(1)	2.68×10^{-3}g	(1)	3×10^{-7}g	~ 100
(2)	6.31×10^{-5}g	(2)	Not detectable	100
(3)	2.78×10^{-4}g	(3)	Not detectable	100

Estimated Gas Composition

(1) 51.4 ppm
(2) 1.0 ppm
(3) 4.5 ppm

EXPERIMENTAL CONDITIONS

Parameter	Sampler No. 1	Sampler No. 2
Solvent	hexane	OSHA-Chromasorb 102
Initial volume	4 ml	N.A.
Pump rate	1 SCFH	1 SCFH
Sampling time	15 min	15 min
Final volume	1 ml	N.A.
Backup solvent	benzene	benzene
Operating temperature	ambient	ambient
Impinger diameter	0.2 cm	N.A.

*Defined as amount collected in sampler divided by total amount collected from that stream, expressed as percentage.